

Test-mass release phase ground testing for the LISA Pathfinder mission

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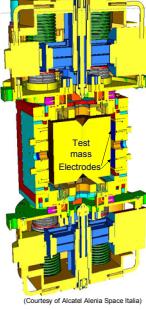
The LISA Test Mass release and adhesion aspects

Abstract

Aim of the LISA Test-flight Package on board the LISA Pathfinder mission is to provide in-flight demonstration of some of the LISA critical technologies in achieving the free-fall condition of a LISA-like test-mass in the bandwidth from 1 to 10 mHz. The 2kg test-mass is suspended by the Gravitational Reference Sensor with millimetre-scale gaps along all axes. Accordingly, owing to high inertial loads during the launch phase the test-mass must be firmly secured to the GRS, in order to avoid collision with its surrounding electrodes and housing parts. After the launch and orbit commissioning, the test-mass must be released to floating conditions, in compliance with strict requirements of initial position and velocity, due to the low force and torque requirements of the GRS adhesion system. The Caging Mechanism Assembly is being designed by Alcatel Alenia Space Italia and it constitutes the GRS subsystem dedicated to cage and release the test-mass. The release phase to floating conditions has been identified as critical for the entire mission, therefore a ground-based verification of such a function has been deemed necessary. The verification approach adopted is to set both test-mass and release-dedicated plunger mock-ups in representative conditions of the final mission situation, which includes the inertial velocity of the test-mass. An effort is being made to build a facility that enables to characterize the momentum transfer between the two suspended bodies and verify the compliance of the design of the release-dedicated mechanism subsystem of the Grabbing Positioning and Release Mechanism of the CMA. The proposed experiment and the facility are here presented and discussed.

Test mass release and capture issue

- TM is a cubic block made of 70% gold / 30% platinum alloy (hard, non-magnetic), coated with pure gold (high IR reflectivity)
- A caging system avoiding any movement of the TM during the launch is necessary.
- TM is pushed against 4 stoppers on an inner face of the sensor housing by a plunger.
- CM must guarantee the release and capture of the TM after launch only relying on the capacitive actuation system.



(Courtesy of Alcatel Alenia Space Italia)

Open issues on the capture procedure

Final release relies on capacitive actuation maximum force = T_{max} or, equivalently, on the maximum kinetic energy that can be taken out of the

$$F_{\text{max}} \approx 0.85 \mu\text{N} \quad d_{\text{max}} \approx 200 \mu\text{m}$$

$$\Rightarrow T_{\text{max}} = F_{\text{max}} d_{\text{max}} \approx 1.7 \cdot 10^{-10} \text{ J}$$

At present:

- No experimental verification that residual adhesion force or imparted kinetic energy are lower than these figures.
- No experimental verification of CM plunger maximum acceleration.

Release approaches

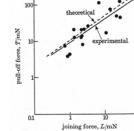
Early stage of Caging Mechanism development:

- Static approach: break the residual adhesion by means of the capacitive actuation.
- Backup: plunger acceleration
- Threshold: micron force authority



Need to quantify the magnitude of the residual adhesion between TM and plunger

Gold/gold static adhesion experimental data



Variation of adhesive force T with joining load L for clean gold specimens in high vacuum (66m crossed cylinders)
(data: N. Plastino, P.P. and Valerio, D., Proc. Royal Soc. London, 1991, 436, 405-419)

First measurement campaign with a modified nanoscratcher at ESTEC showed a pull-off force that ranged from 0.03mN to 0.67mN (gold-coated spheres on gold-coated Au-Pt substrate and optically finished gold-coated surface).



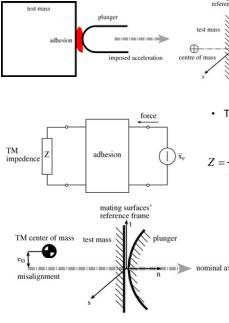
Need for a dynamic release

Requirement of 5micron's maximum allowed velocity of the TM

The ground testing validation of the LISA TM release mechanism

In-flight release scenario

- Only nominal stress allowed on the patch (0.3micron maximum deviation due to S/C acceleration)



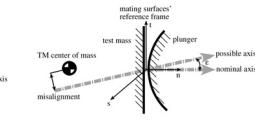
TM mechanical impedance constitutes the load

$$Z = \frac{\ddot{x}}{F} = \frac{1}{m} + \left(\frac{e_a + \frac{L}{2} \sin \varepsilon}{I} \right)^2$$

$$e_a = 1\text{mm}$$

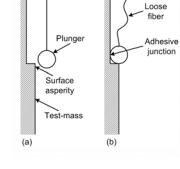
$$\varepsilon = 50\text{mrad}$$

$$\Delta t = 1.3\%$$



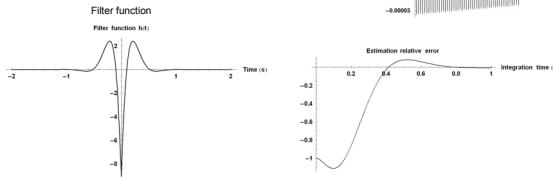
Guidelines for the experiment design

- The measurement of transferred momentum must be representative of the in-flight conditions
- Soft suspension along the direction of retraction
- Limited shear stress at the contact patch
 - Very light plunger mock-up
 - Fiber tension measurement (also for impulse vertical component)
 - Soft lateral constraint
- Rejection to ground micro-seismic activity (kinetic energy <AU)
- Variation of direction of retraction



A simulated release experiment

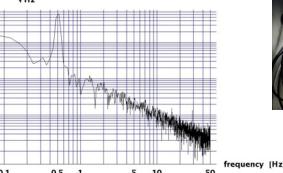
- Test mass displacement signal with predicted noise (seismic+instrumental)
- Horizontal displacement noise PSD has been assumed constant in acceleration and equal to $10^{-12} \text{ m}^2/\text{Hz}$
- Position read-out noise PSD has been assumed constant and equal to $10^{-16} \text{ m}^2/\text{Hz}$
- Optimal filtering for impulse detection (Wiener-Kolmogorov): $\sigma = 10^{-8} \text{ g} \cdot \text{m/s}$ (0.1kg test mass)



Development status of the Transferred Momentum Measurement Facility



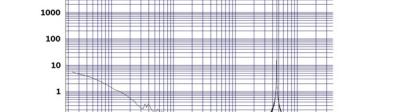
Position measurement noise [$\mu\text{m}/\sqrt{\text{Hz}}$]



Rejection to ground microseismic activity

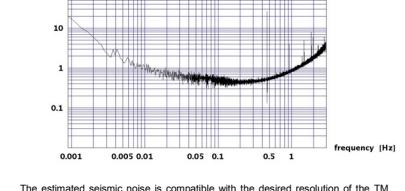
- Spectral density of TM position signal measured by laser interferometer

$$\text{displacement noise } [\frac{\mu\text{m}}{\sqrt{\text{Hz}}}]$$



- Spectral density of seismic acceleration derived from TM displacement noise

$$\text{seismic acceleration } [\frac{\mu\text{m}/\text{s}^2}{\sqrt{\text{Hz}}}]$$



The estimated seismic noise is compatible with the desired resolution of the TM linear momentum measurement (2% of the maximum linear momentum allowed in the LISA TM release).